

Composition of the Asian summer monsoon anticyclone: Climatology and variability from 10 years of Aura Microwave Limb Sounder measurements

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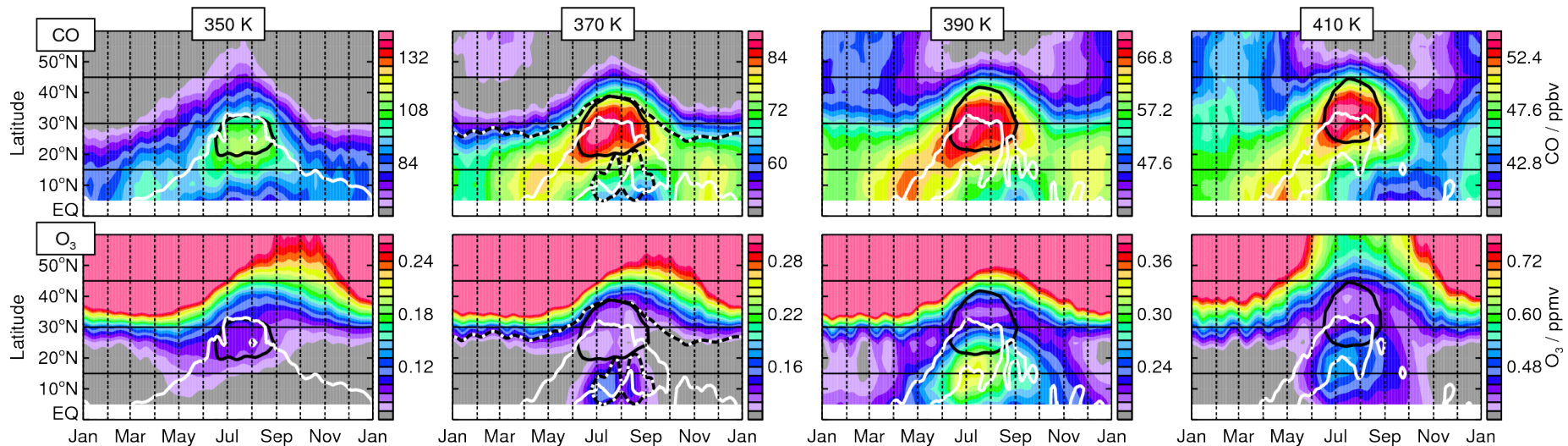
- ✦ The Asian summer monsoon (ASM) is the dominant climatological feature of the circulation in the upper troposphere / lower stratosphere (UTLS) during boreal summer and thus has a strong impact on the global atmosphere
- ✦ Satellite measurements are invaluable for investigating the composition of the ASM anticyclone, which has been sparsely sampled by other means
- ✦ MLS makes simultaneous co-located measurements of several trace gases and cloud ice water content (IWC, a proxy for deep convection) in the UTLS on a daily basis
- ✦ In this talk, we capitalize on the dense spatial and temporal sampling, long-term data record, and extensive measurement suite of Aura MLS
- ✦ We use version 4 MLS measurements of both tropospheric (H_2O , CO , CH_3Cl , CH_3CN , CH_3OH) and stratospheric (O_3 , HNO_3 , HCl) tracers, as well as IWC, to develop a comprehensive climatology of the composition of the ASM anticyclone



- ✦ We focus on climatological behavior, averaged over 10 years (2005–2014)
- ✦ We define the general ASM region to lie within the $15\text{--}45^\circ\text{N} \times 10\text{--}130^\circ\text{E}$ “box”
- ✦ To encompass the deep structure of the ASM circulation, MLS data are interpolated to 4 potential temperature surfaces in the UTLS, corresponding (within the box) to:

Potential Temperature Surfaces (K)	Corresponding MLS Retrieval Pressure Surfaces (hPa)	Corresponding Approximate Altitude (km)
410	100–68	16.5–18.5
390	121–82	15–17.5
370	147–100	13–16.5
350	261–177	10–13

- ✦ We use Montgomery stream function (MSF) to identify the closed circulation of the ASM anticyclone



- ✦ Time series calculated over the longitudes of the ASM box as a function of latitude and potential temperature
- ✦ The full annual cycle is shown to put the ASM in context
- ✦ MLS CO and O₃ serve as representative tropospheric and stratospheric tracers, respectively
- ✦ White contours show MLS IWC to identify regions / times of vigorous deep convection; black show MSF
- ✦ Dashed black-and-white contour at 370 K denotes the climatological dynamical tropopause (3 PVU)

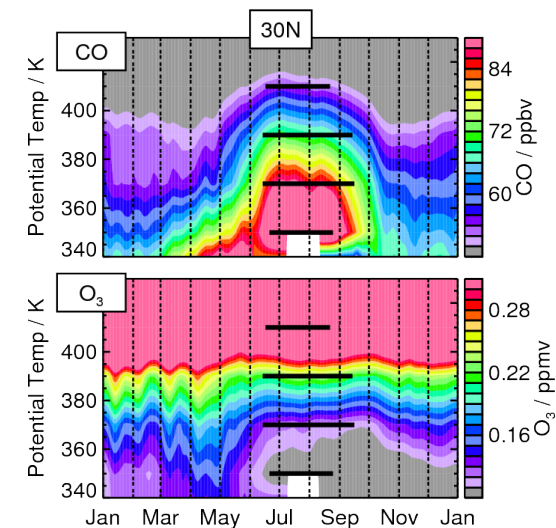
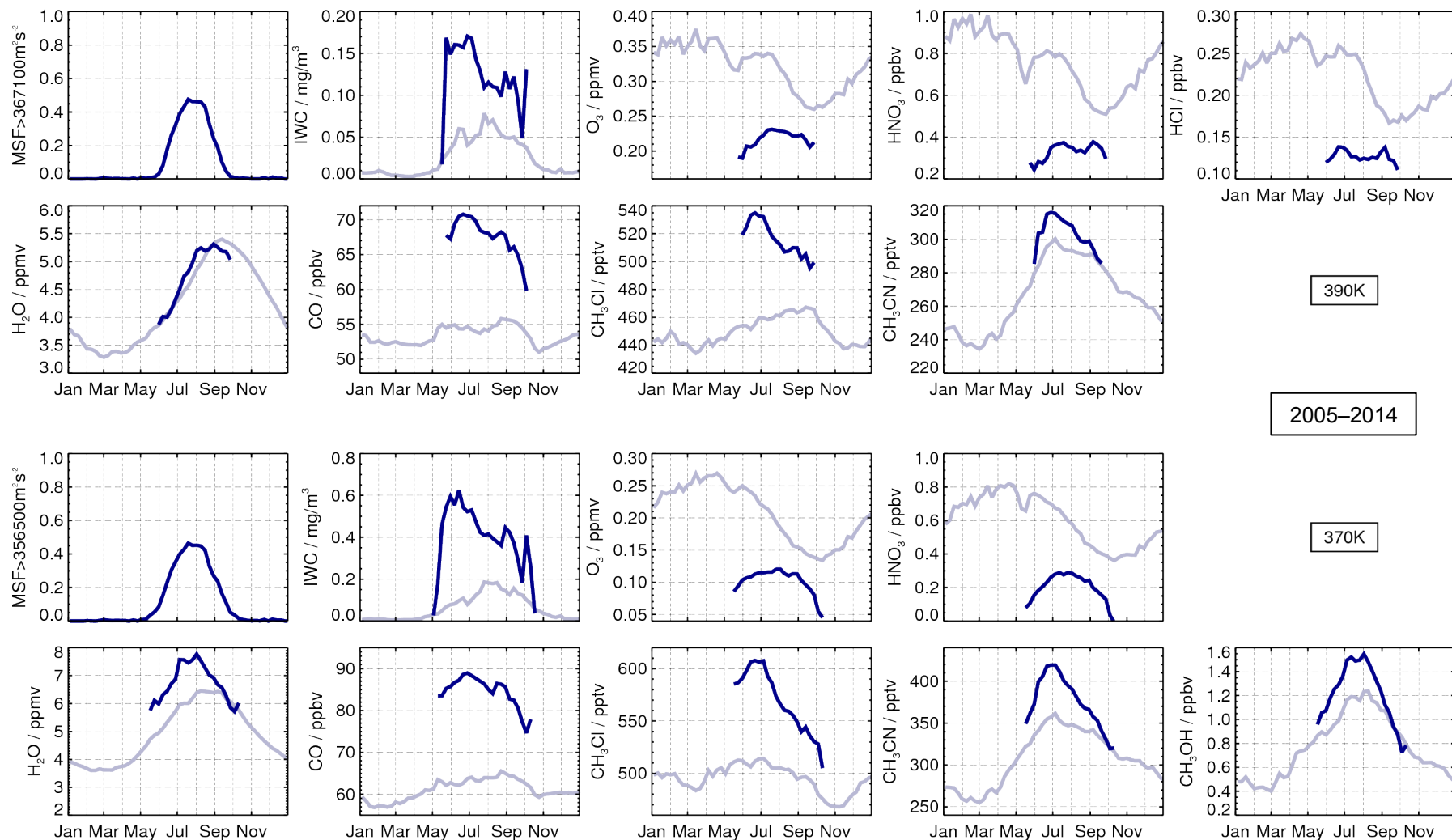
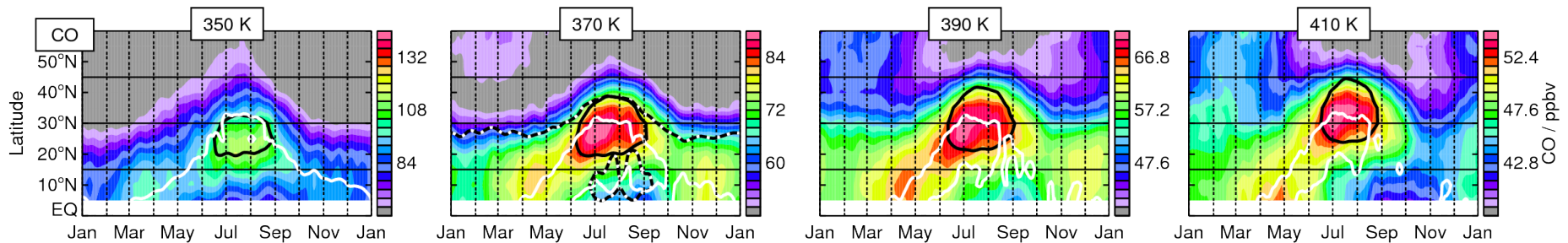


Figure intro: Climatological evolution in / out of anticyclone

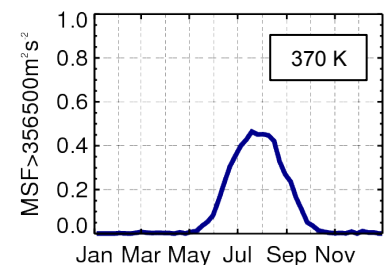
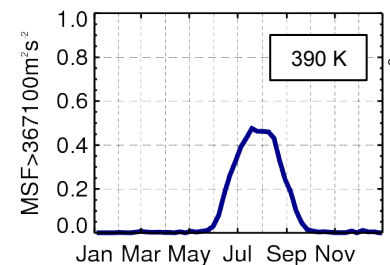
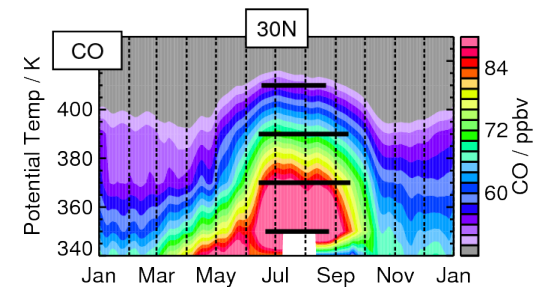
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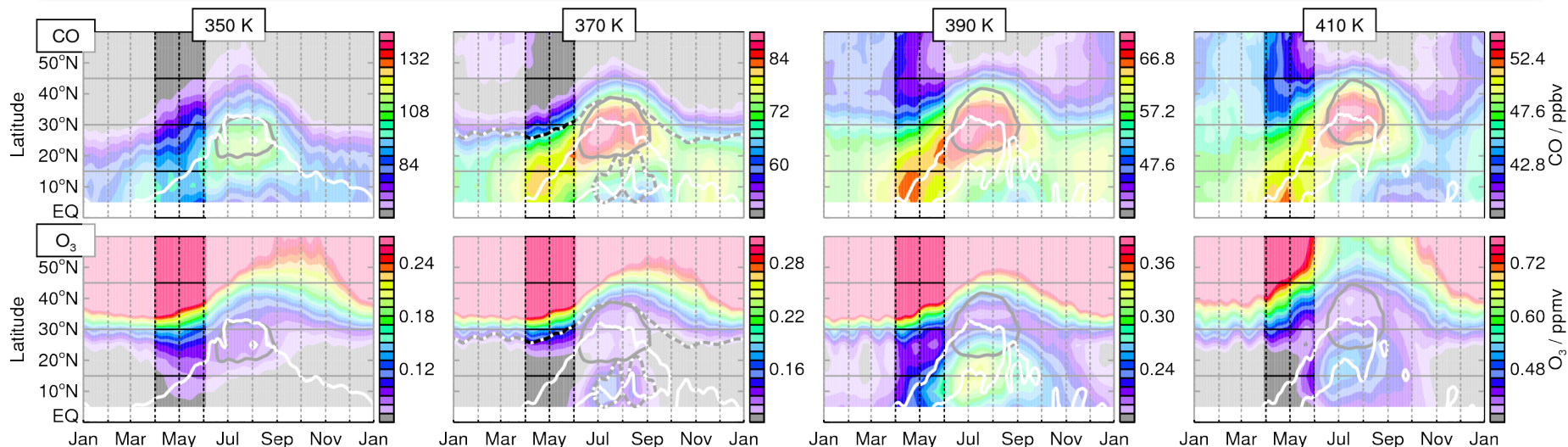


- ✦ Weekly averages of MLS measurements inside the anticyclone compared to the annual cycle observed in each species over the rest of the hemisphere (0°-180°E) outside the anticyclone but still within the latitude range of the ASM box

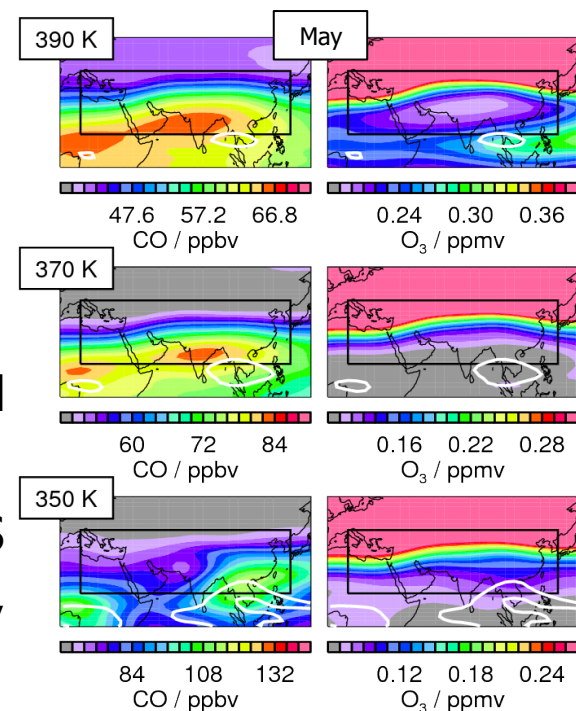


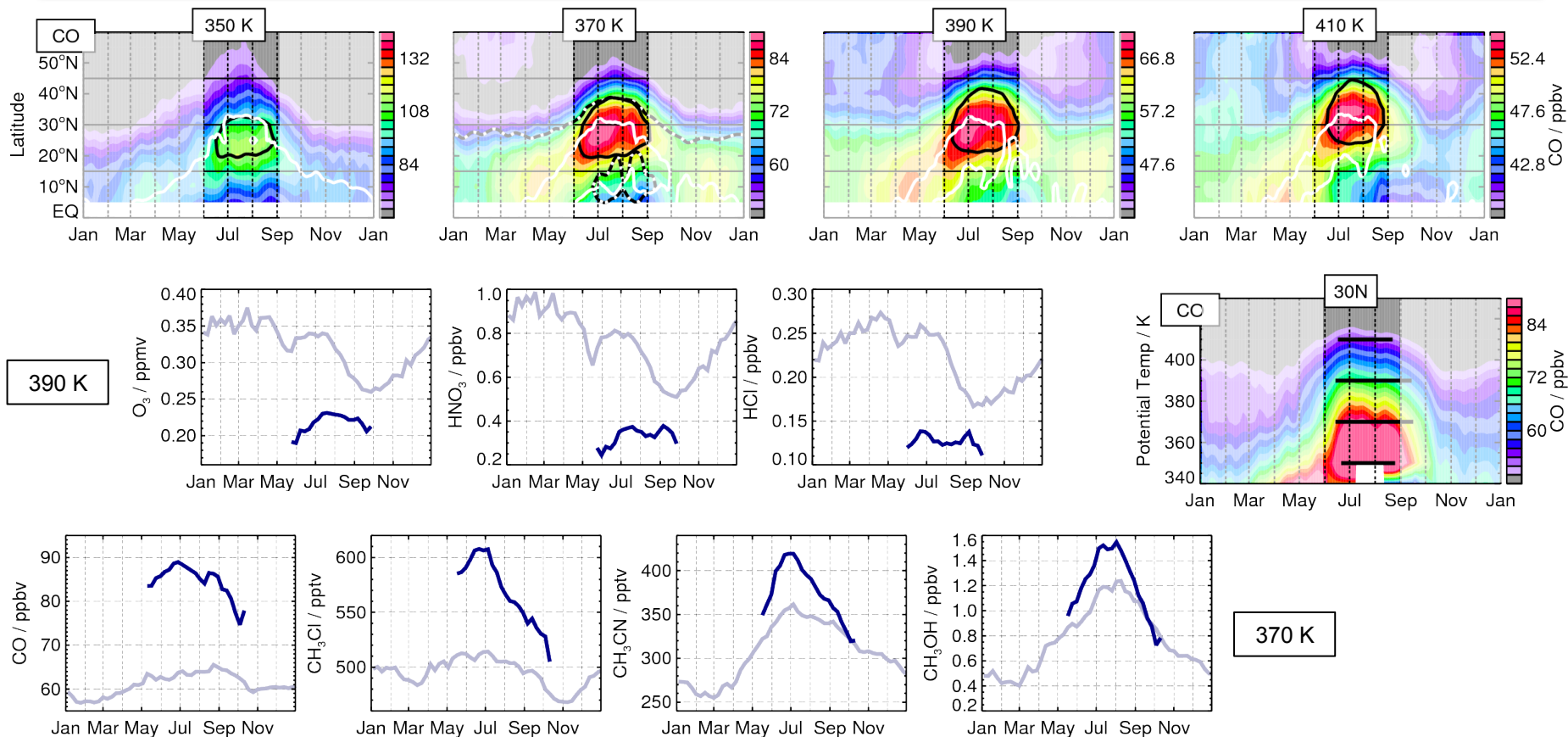
- ✦ The evolution of the ASM anticyclone is marked in black
- ✦ A slight ($\sim 5^\circ$) south-to-north shift is seen between MSF contours at the lowest and the highest levels, reflecting the northward tilt of the ASM anticyclone with altitude
- ✦ The anticyclone spins up earlier and decays later at the middle two isentropes than it does at 350 or 410 K, resulting in a difference in its climatological lifetime of about a month between the levels
- ✦ At 370 and 390 K, the anticyclone starts to occupy a sizeable fraction of the hemisphere by early June, fills nearly 50% of it in mid-July through early August, begins to decay thereafter, and dissipates completely by late September (390 K) or early October (370 K)



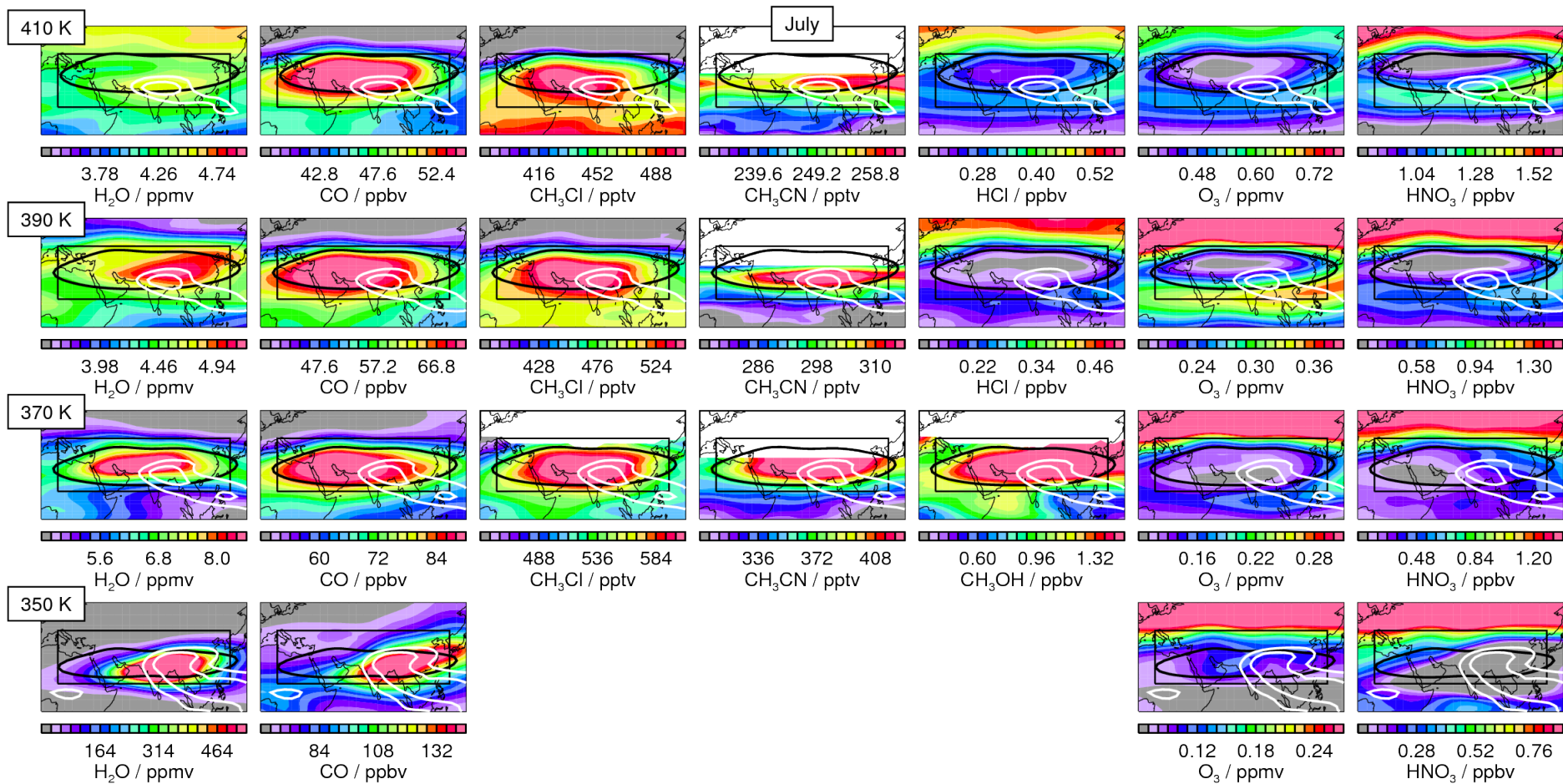


- ✦ The anticyclone moves northward, accompanied by the poleward migration and weakening of the subtropical westerly jet, whose core coincides with the tropopause
- ✦ The summertime poleward shift of the tropopause is reflected in the characteristic “curvature” in the fields
- ✦ Although the climatological anticyclonic circulation is still weak, CO is already somewhat enhanced at 350–390 K; convection has begun to penetrate deeply into the UTLS
- ✦ Some pollution entrained into the proto-anticyclone may originate from biomass burning in Africa in prior months

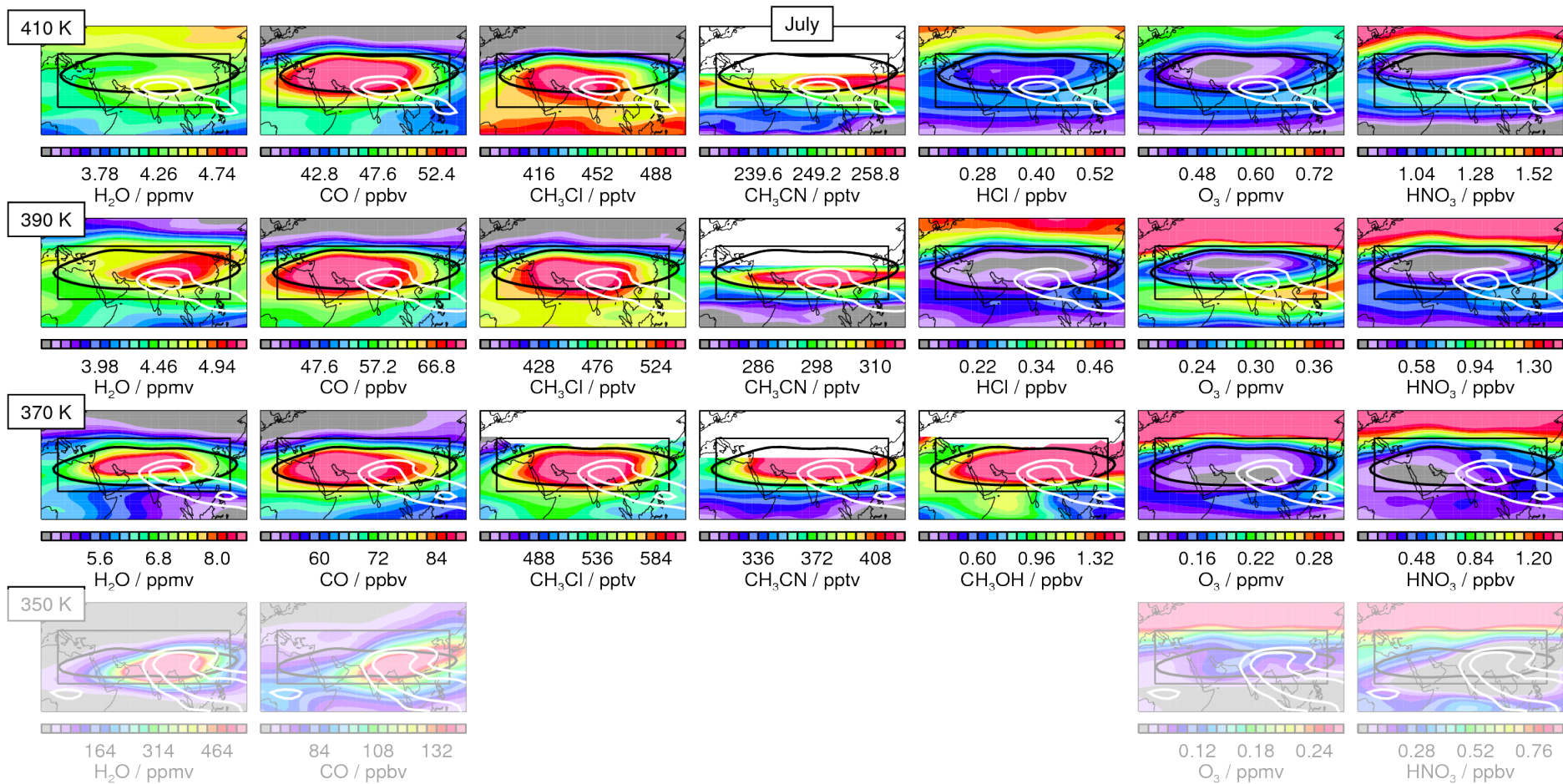




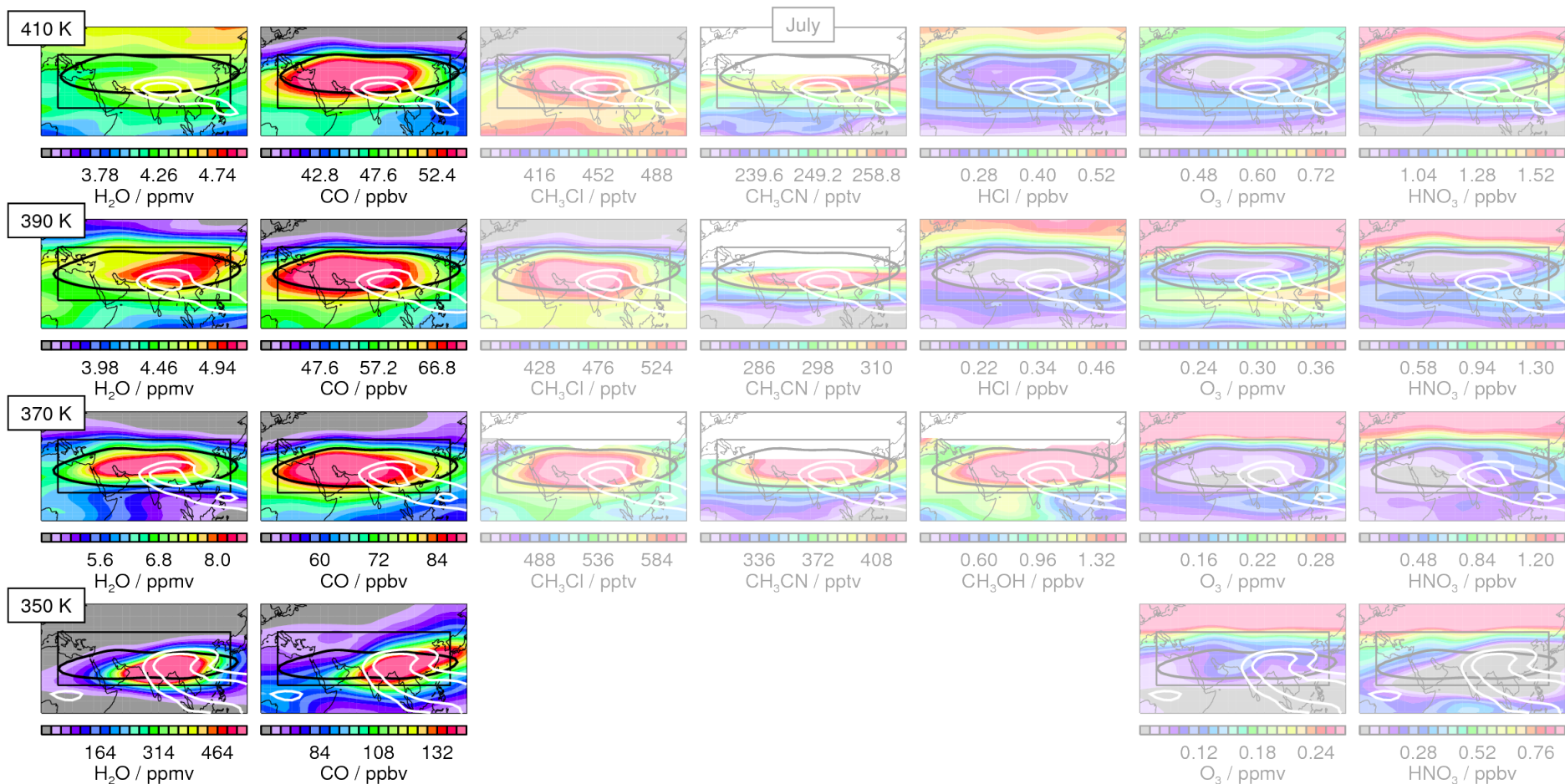
- ✦ Inside the developed anticyclone, tropospheric and stratospheric tracers exhibit substantial changes, not only from their pre-monsoon distributions in the ASM region but also from their summertime distributions in the rest of the hemisphere
- ✦ Pronounced enhancements in the tropospheric tracers extend up to 410 K
- ✦ The largest abundances of the pollution markers are seen in June and July



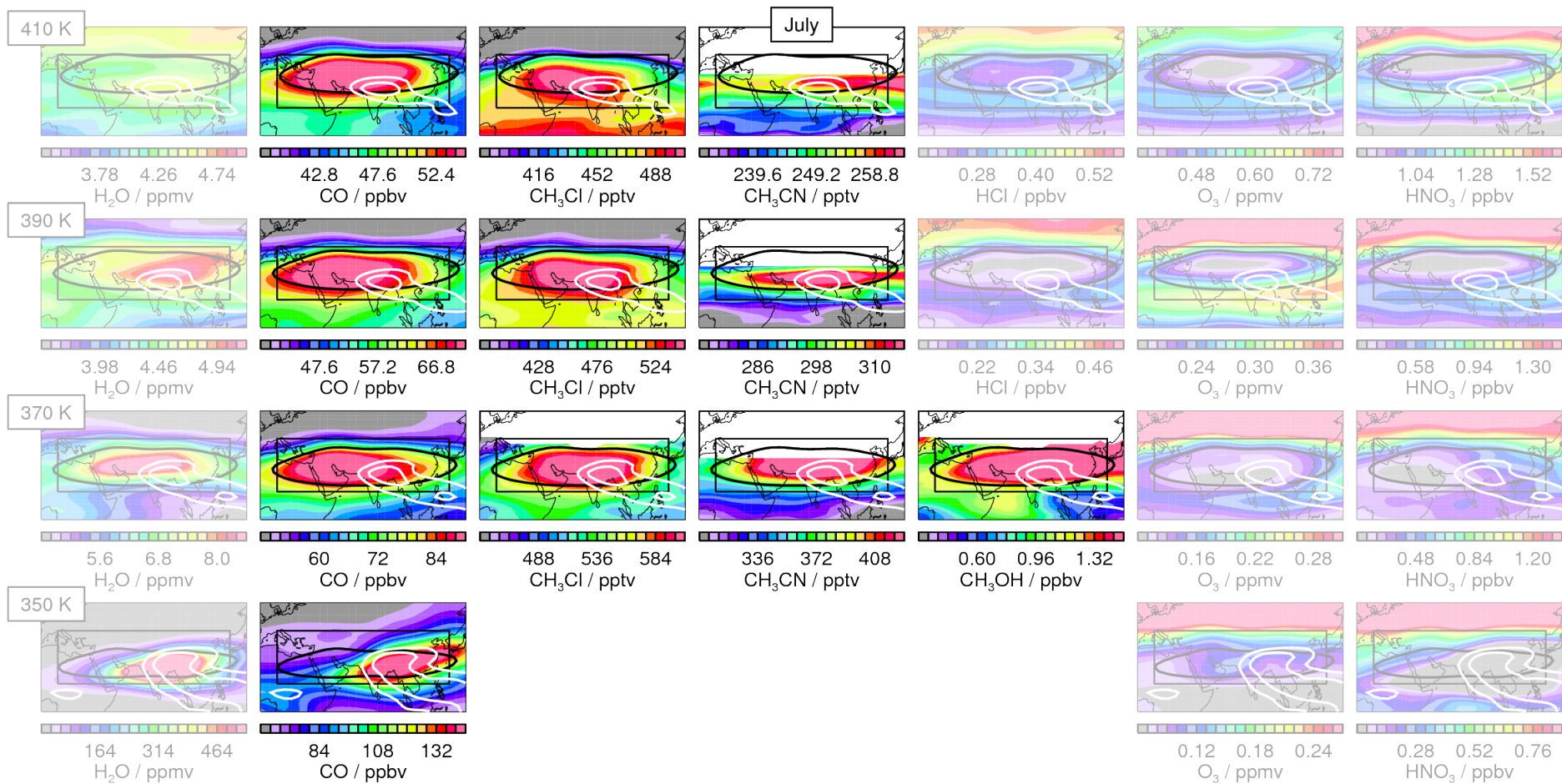
- ✦ The strong anticyclonic circulation (indicated by MSF, black contours) is generally situated to the northwest of the main climatological region of intense deep convection (indicated by MLS IWC, white contours)



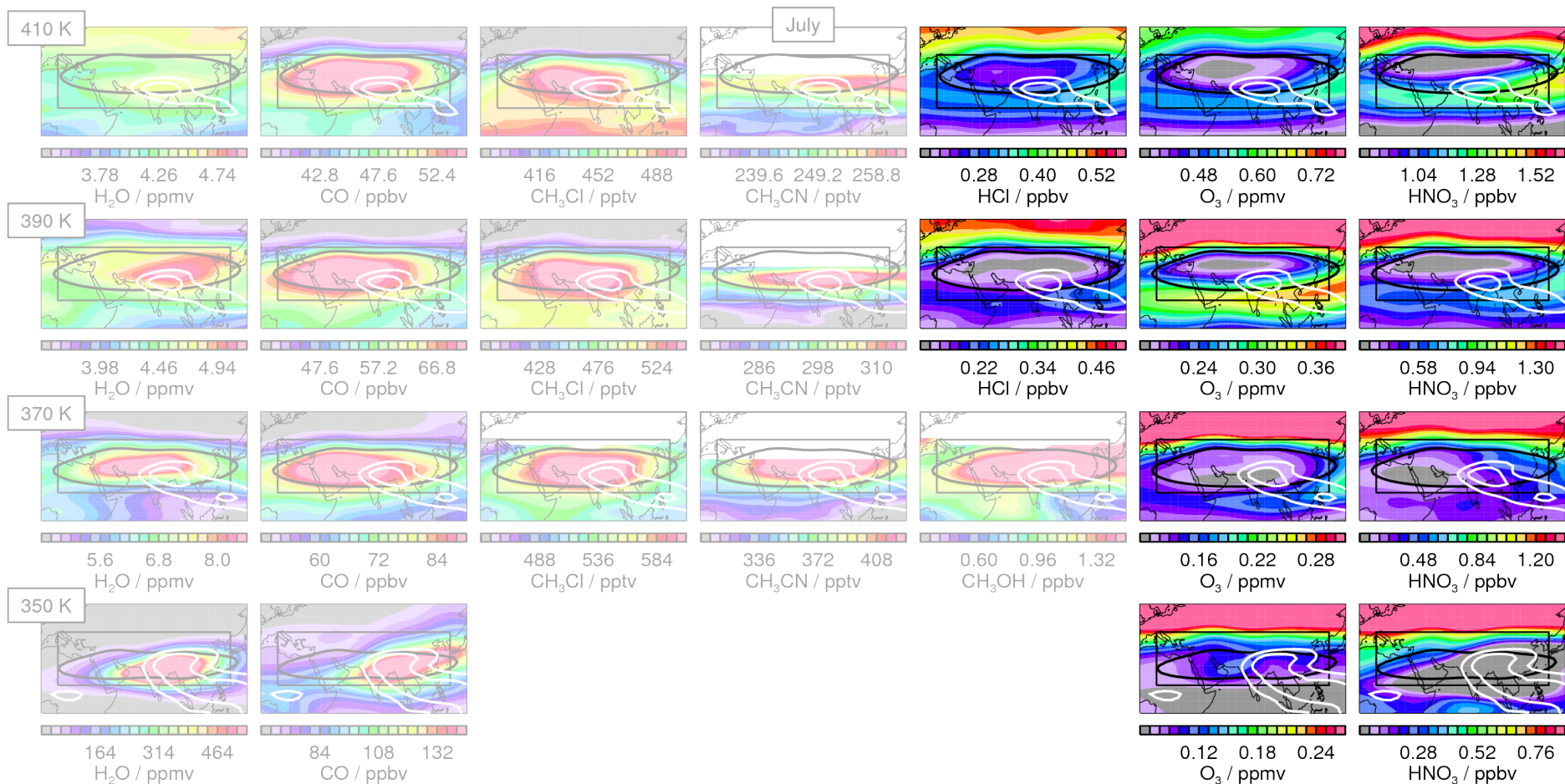
- ✦ The geographic location and exact timing of extreme values vary from species to species, but above 350 K the enhancements or depressions in the trace gases are aligned more closely with the anticyclone than with the area of convective activity



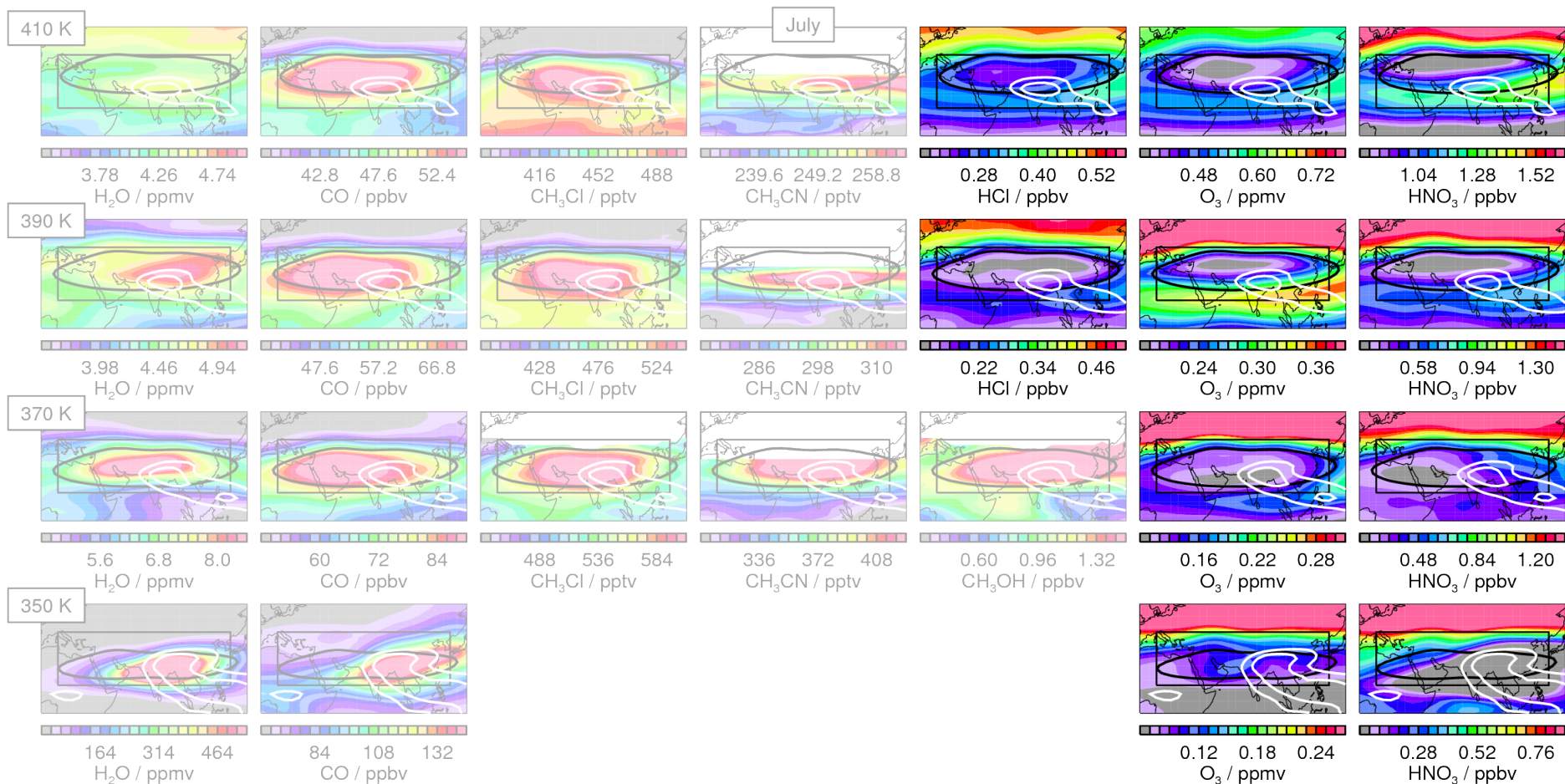
- ✦ At 350 K, the distributions of both H₂O and CO are more congruent with the broad region of intense convection than with the MSF contour, implying greater direct convective influence at this level
- ✦ Thus enhancements are persistently shifted further west at 370 K than at 350 K



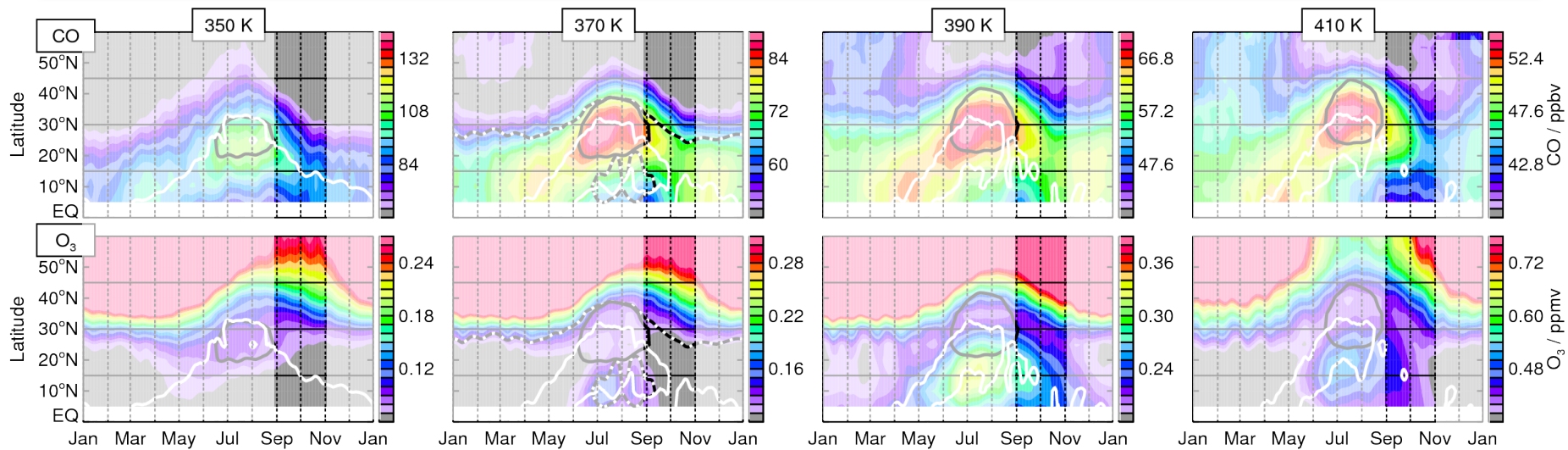
✦ In addition to CO, pronounced enhancements in the ASM anticyclone are seen in other markers of pollution measured by MLS, such as CH₃Cl, CH₃CN, and CH₃OH



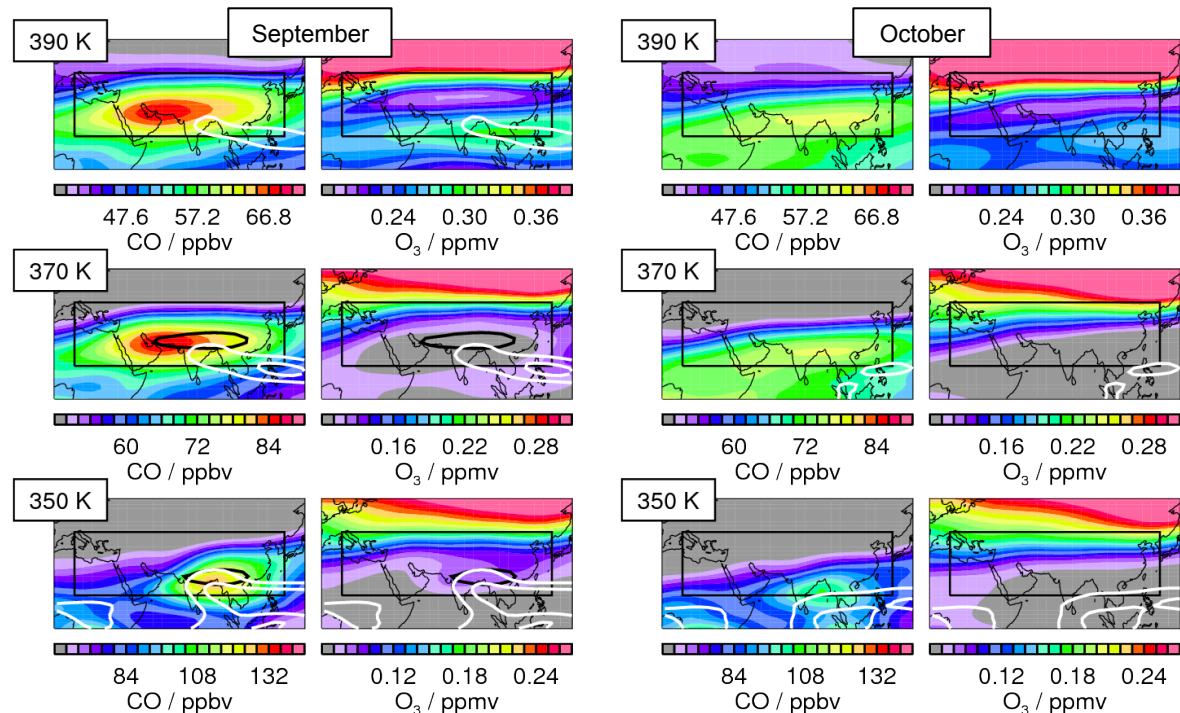
- ✦ Lofting of near-surface air generally decreases O₃ inside the anticyclone; HNO₃ abundances are also typically smaller in the upper troposphere than stratosphere
- ✦ Accordingly, minimum values of the stratospheric tracers are observed in the deep core of the anticyclone in July and August



- ✦ Photochemical production can confound interpretation of O₃ in the ASM area, and local sources (e.g., lightning) and sinks (e.g., cirrus clouds) can also affect HNO₃
- ✦ In contrast, HCl has no significant sources in the upper troposphere, thus entrainment of lower-level air leads to a clear minimum in HCl in the anticyclone



- ✦ After August, the subtropical westerly jet / tropopause gradually migrates back toward the equator
- ✦ By October, only small perturbations still linger in most of the trace gas distributions



✦ Summary:

- ✧ Aura MLS provides a long-term daily global data set of simultaneous and co-located measurements of an extensive suite of stratospheric and tropospheric tracers and cloud ice of great value for monsoon studies
- ✧ We are using v4 MLS data to characterize the climatology of UTLS trace gas distributions in the ASM region and quantify their spatial and seasonal variability

✦ Additional studies currently ongoing:

- ✧ Investigation of interannual variability in the UTLS response to the ASM
- ✧ Correlation of the observed trace gas behavior in the ASM region with variations in surface emissions and meteorological factors, such as existence dates, location, size, and strength of the anticyclone; the location and strength of deep convection; diagnostics of local mixing; variations in the latitude, altitude, depth, and strength of the upper tropospheric jets; ENSO and QBO indices; etc.
- ✧ Evaluation of the representation of the ASM in chemistry climate models, such as CAM-Chem